High temperature continuous wave operation of InAs quantum dot lasers near 1.3 μm

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InAs dot lasers near 1.3 μm have been demonstrated continuous wave (CW) operation with output power of 15 mW/facet at temperature of 100°C. The characteristic temperature T_o for ground state CW lasing is 78 K up to 100°C.

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Despite significant improvements in recent years, quantum dot (QD) lasers still have difficulties operating at the ground state without high reflectivity coating[1], either show a characteristic temperature T_o abruptly decreasing at or above room temperature[2] or switch to higher energy lasing states[3]. For reducing the temperature sensitivity, one approach is using deep potential wells to thermally decouple the QD ground state from the wetting layer and by designing QDs to have a wide energy separation between the ground and first excited. But a more fundamental approach is to increase the gain of QD ground state[1], by packing more dots in the active region and reducing the inhomogeneous broadening. We report here high performance narrow ridge waveguide InAs QD edge-emitting lasers lasing CW at ground state near 1.3 μm up to the temperature of 100°C.

These lasers are based on four stack InAs QDs embedded within strained InGaAs quantum well, with dot density of 10^{11} cm^{-2}, and fabricated using narrow ridge waveguide design with ridge width of 5 μm. Ground state CW lasing has been achieved at room temperature, showing lasing wavelength between 1.25~1.26 μm. Then depend on cavity length, with increasing injection current- CW lasing continues at ground state (for 1 mm, 1.5 mm cavity length) or switches to the first excited state at wavelength of 1.20~1.22 μm (for 500 μm, 750 μm cavity length). Fig.1 plots ground state CW lasing spectra of a 1 mm cavity laser, showing the lasing wavelength of 1.3 μm at 90°C with 90 mA injection current. For 1 mm and 1.5 mm cavity length lasers, ground state CW lasing was even obtained up to 100°C, which is the temperature limit of the thermoelectric cooler. To our knowledge, this is so far the highest temperature ever reported for QD lasers lasing CW at ground state near 1.3 μm. With increasing temperature, a wavelength shift of 3.7 Å/K is found for these QD lasers, comparable to that of quantum well lasers, which is bigger than 2 Å/K reported for QD lasers at wavelength near ~ 1 μm[4]. The temperature dependence of gain peak for both QD and quantum well depend on the bandgap of the active material and the barriers, if state filling happens in QD due to limited dot density, the blue shift of state filling will partially compensate for the temperature dependence of the bandgap. Therefore in our case, multi stack and high dot density of $\sim 10^{11}$ cm^{-2} QDs obviously provided

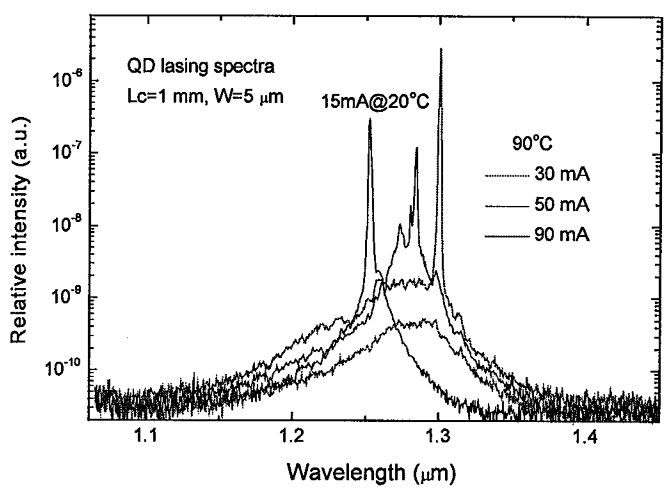

Fig.1 Ground state CW lasing spectra at 90°C of a 1 mm cavity length laser measured at various currents, indicating a ground state lasing wavelength of 1.3 μm. For comparison a spectrum at 20°C shown.

enough gain for lasing CW at ground state, and the state filling is negligible for 1 mm and 1.5 mm cavity lasers.

As mentioned above, for both 1 mm and 1.5 mm long lasers, CW ground state lasing were obtained at any injection current until thermal roll over up to the temperature of 100°C, which is the limit of our thermoelectric cooler. Fig. 2 shows the single facet light output characteristics versus current of a 1.5 mm cavity length laser operating CW measured at different temperature. At room temperature, the threshold current and threshold current density is about 10 mA, 133 A/cm^{-2} respectively, the single facet output power exceeds 50 mW and the differential slope efficiency is 55%. Due to the smaller power dissipation of a very narrow stripe ridge waveguide structure, thermal rollover is reduced and CW lasing occurs even at an injection current of $I > 20I_{th}$. While at the temperature of 100°C, the threshold current and threshold current density are about 33 mA, 440 A/cm^{-2} respectively, the single facet output power exceeds 15 mW and the differential slope efficiency is 35%.

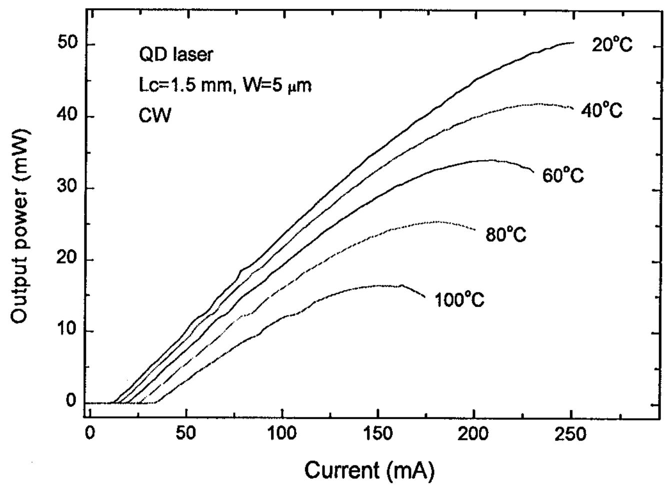

Fig.2 Light versus current for a 1.5 mm cavity length laser without facet coating measured at different temperature.

The temperature dependence of the threshold current of a 1.5 mm cavity length QD laser has been measured for ground state lasing under both CW and pulsed operation (5 μs pulses with a duty cycle of 0.5%). For temperature ranging from 283 K to 373 K, the characteristic temperatures T_o are 78 K for CW operation, and 86 K for pulsed operation. To our knowledge, the 78 K characteristic temperature is the largest reported value in this temperature range for ground state CW operation of a QD laser. Comparing with either low T_o or shifting to excited state lasing reported previously[3,5], multi stack and high QD density of ~10^{11} cm^{-2} thus larger gain are the key reasons for achieving ground state lasing with temperature insensitive threshold current for temperatures up to 100°C.

In summary, we have demonstrated high performance temperature insensitive narrow ridge waveguide QD lasers near 1.3 μm using four stacks of InAs QD layer embedded within strained InGaAs quantum wells as an active region. For a 1.5 mm long cavity QD laser, ground state CW lasing has been achieved with single facet output power of 15 mW and a differential slope efficiency of 35% at temperature as high as 100°C, while at room temperature having a differential quantum efficiency about 55% and single facet output power of 50 mW. The characteristic temperature T_o for ground state CW lasing is 78 K at temperatures ranging from 20°C to 100°C.

Reference

1. N. Hatori, M. Sugawara, K. Mukai, Y. Nakata, and H. Ishikawa, Appl. Phys. Lett. 77, 773(2000).
2. G. Park, D. L. Huffaker, Z. Zou, O. B. Shchekin, and D. G. Deppe, IEEE Photo. Technol. Lett. 11, 301(1999).
3. X. Huang, A Stintz, C. P. Hains, G. T. liu, J. Cheng, and K. J. Malloy, IEEE Photo. Technol. Lett. 12, 227(2000).
4. F. Schafer, J. P. Reithmaier, and A. Forchel, Appl. Phys. Lett. 74, 2915(1999).
5. O. B. Shchekin, G. Park, D. L. Huffaker, Q. Mo, and D. G. Deppe, IEEE Photo. Technol. Lett. 12, 1120(2000).